EXHIBIT E

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(54) SINGLE-MODE AMPLIFIERS AND COMPRESSORS BASED ON MULTI-MODE FIBERS

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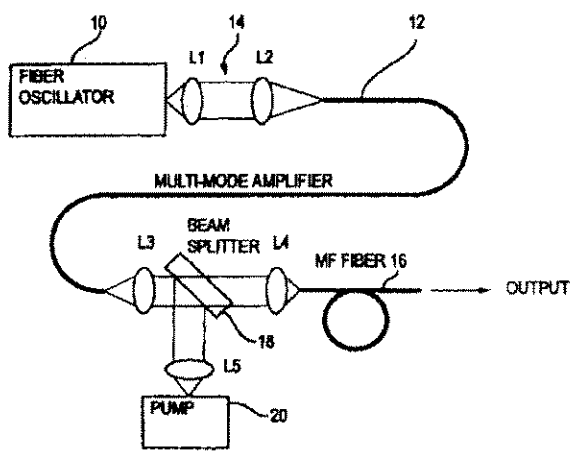
(57) **ABSTRACT**

To amplify and compress optical pulses in a multi-mode (MM) optical fiber, a single-mode is launched into the MM fiber by matching the modal profile of the fundamental mode of the MM fiber with a diffraction-limited optical mode at the launch end. The fundamental mode is preserved in the MM fiber by minimizing mode-coupling by using relatively short lengths of step-index MM fibers with a few hundred modes and by minimizing fiber perturbations. Doping is confined to the center of the fiber core to preferentially amplify the fundamental mode, to reduce amplified spontaneous emission and to allow gain-guiding of the fundamental mode. Gain-guiding allows for the design of systems with length-dependent and power-dependent diameters of the fundamental mode. To allow pumping with high-power laser diodes, a double-clad amplifier structure is employed. For applications in nonlinear pulse-compression, self phase modulation and dispersion in the optical fibers can be exploited. High-power optical pulses may be linearly compressed using bulk optics dispersive delay lines or by chirped fiber Bragg gratings written directly into the SM or MM optical fiber. High-power cw lasers operating in a single near-diffraction-limited mode may by constructed from MM fibers by incorporating effective mode-filters into the laser cavity. Regenerative fiber amplifiers may be constructed from MM fibers by careful control of the recirculating mode. Higher-power Q-switched fiber lasers may be constructed by exploiting the large energy stored in MM fiber amplifiers.



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EX PARTE REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **1-49** is confirmed.

New claims **50-64** are added and determined to be patentable.

50. An optical amplification system according to claim 1, wherein said mode converter comprises an optical fiber spliced to an input of said multimode fiber.

51. The optical amplification system according to claim 50, wherein said spliced fiber comprises a single-mode fiber, and wherein the mode of the single mode fiber is matched to the fundamental mode of said multi-mode amplifier.

52. An optical amplification system, comprising:

a laser source generating an input beam having a nearly diffraction limited mode;

a multi-mode fiber amplifier, said multi-mode fiber amplifier comprising a bent fiber having a bend radius in the range from about 5 cm to 50 cm;

a mode converter receiving the input beam and converting the mode of the input beam to match a fundamental mode of the multi-mode fiber amplifier, and providing a mode-converted input beam to said multi-mode fiber amplifier; and

a pump source coupled to said multi-mode fiber amplifier, said pump optically pumping said multi-mode fiber amplifier, said multi-mode fiber amplifier providing at an output thereof an amplified beam substantially in the fundamental mode.

53. An optical amplification system, comprising:

a laser source generating an input beam having a nearly diffraction limited mode;

a multi-mode fiber amplifier;

a mode converter receiving the input beam and converting the mode of the input beam to match a fundamental mode of the multi-mode fiber amplifier, and providing a mode-converted input beam to said multi-mode fiber amplifier; and

a pump source coupled to said multi-mode fiber amplifier, said pump optically pumping said multi-mode fiber amplifier, said multi-mode fiber amplifier providing at an output thereof an amplified beam substantially in the fundamental mode, and wherein said multi-mode fiber amplifier is configured to substantially eliminate mode coupling during propagation of said mode converted beam in said multi-mode fiber amplifier.

54. The optical amplification system according to claim 53, wherein said mode coupling couples less than 6% of the fundamental mode to one or more higher order modes.

55. An optical amplification system, comprising:

a laser source generating an input beam having a nearly diffraction limited mode;

a multi-mode fiber amplifier;

a mode converter receiving the input beam and converting the mode of the input beam to match a fundamental mode of the multi-mode fiber amplifier, and providing a mode-converted input beam to said multi-mode fiber amplifier;

a pump source coupled to said multi-mode fiber amplifier, said pump optically pumping said multi-mode fiber amplifier, said multi-mode fiber amplifier providing at an output thereof an amplified beam substantially in the fundamental mode; and

a single mode fiber receiving the amplified beam.

56. The optical amplification system according to claim 55, wherein a coupling efficiency between said amplifier and said single mode fiber is about 90%.

57. The optical amplification system according to claim 55, wherein said multi-mode amplifier is substantially straight.

58. The optical amplification system according to claim 55, wherein said amplifier is configured with a sufficient thickness to limit bend induced mode coupling.

59. An optical amplification system, comprising:

a laser source generating an input beam having a nearly diffraction limited mode, said laser source comprising a cw fiber laser;

a multi-mode fiber amplifier;

a mode converter receiving the input beam and converting the mode of the input beam to match a fundamental mode of the multi-mode fiber amplifier, and providing a mode-converted input beam to said multi-mode fiber amplifier; and

a pump source coupled to said multi-mode fiber amplifier, said pump optically pumping said multi-mode fiber amplifier, said multi-mode fiber amplifier providing at an output thereof an amplified beam substantially in the fundamental mode.

60. The optical amplification system according to claim 59, wherein said cw fiber laser comprises a multi-mode fiber amplifier.

61. The optical amplification system according to claim 59, wherein said cw fiber laser comprises an intracavity mode filter.

62. The optical amplification system according to claim 59, further comprising at least one pre-amplifier disposed between said source and said multi-mode fiber amplifier.

63. The optical amplification system according to claim 62, wherein a core radius of said pre-amplifier is smaller than a radius of said multimode fiber amplifier.

64. An optical amplification system, comprising:

a laser source generating an input beam having a nearly diffraction limited mode;

a multi-mode fiber amplifier;

a mode converter receiving the input beam and converting the mode of the input beam to match a fundamental mode of the multi-mode fiber amplifier, and providing a mode-converted input beam to said multi-mode fiber amplifier; and

a pump source coupled to said multi-mode fiber amplifier, said pump optically pumping said multi-mode fiber amplifier, said multi-mode fiber amplifier providing at an output thereof an amplified beam substantially in the fundamental mode, and wherein said multi-mode fiber amplifier is configured to provide a nearly diffraction limited output beam.

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